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The Influence of Heterogeneous Container Materials Subjected to Thermal Stress on Bisphenol A Emission

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ABSTRACT

Bisphenol-A (BPA) has presented itself as a major carcinogen in many consumer goods. Numerous household products, specifically water bottles, contain high amounts of BPA that are potentially toxic when ingested. Research indicates that certain materials are prone to leaching high BPA levels under exposure to heat or extended usage. The purpose of this research is to investigate the impact of specific material types including stainless steel, tin, polycarbonate plastics, and aluminum with epoxy resins on human health. It was expected that if the material, polycarbonate plastic, is used to contain water and kept in a warm environment (32.2°C), then it will have the most amount of Bisphenol A production. 25 samples of stainless steel, polycarbonate plastic, tin-plated bottle, aluminum with epoxy resins were filled with 12 oz of water and heated to (32.2°C) for 12 hours. Afterward, Bisphenol A Indicator Iron (III) Chloride was used and BPA testing swabs and a color chart were used to test the BPA in each container. Results showed that polycarbonate plastics had the highest average BPA production with 6.344 ng/mL of BPA. The rationale behind this study is to raise awareness about the detrimental effects of BPA on the human body. A future implication of this research could be to help encourage the creation of BPA-free materials that are related to human consumption. Additionally, these findings could provide guidelines to create industry standards and policies to limit BPA use.

Introduction

Worldwide, many household products are being mass-produced with low-grade, cheap materials that are being sold to everyday individuals. These consumer goods can be particularly harmful when they encounter food and beverages, as BPA can leach into the contents, potentially disrupting hormonal balance, impairing reproductive health, and increasing the risk of conditions such as diabetes and cardiovascular disease due to its widespread use in materials used to package, store, and consume both food and liquids.

Following BPA exposure, people face a wide range of negative health effects that directly impact endocrine function, reproductive health, and overall metabolic processes. BPA's phenolic structure allows the chemical to act on estrogen receptors as a hostile, disrupting and altering signaling pathways such as the ERK/MAPK pathway, which is involved in cell growth and differentiation, and the PI3K/Akt pathway, which regulates cell survival and metabolism (Michałowicz & Krol, 2016). As a result, BPA aids in the pathogenesis of numerous endocrine disorders including male and female sterilization, hormone-dependent tumors such as breast and prostate cancer, precocious puberty, and multiple metabolic disorders such as polycystic ovary syndrome (Konieczna, 2015).

BPA further impacts global populations as human exposure to BPA is ubiquitous due to its high-volume production and use throughout several global industries (Sonavane, 2019). This was observed in 2022 when an estimated 10.6 million tons of BPA were produced globally (Sonavane, 2019). BPA has been shown to directly impact humans due to its prevalence in consumer products; the Centers for Disease Control and Prevention found detectable levels of BPA in 93% of 2517 urine samples from people six years and older in 2003-2004 (Calafat, 2008).

Based on the evidence suggesting that higher temperatures and lengthy use accelerate the leaching of BPA, drinking water containers composed of polycarbonate plastics are predisposed to releasing elevated levels of this chemical. It is hypothesized that polycarbonate plastic containers, when exposed to a warm environment (32.2°C), will produce the highest amount of Bisphenol A. These containers represent the various types of bottles that several global populations could be drinking from. Depending on the material, BPA is commonly used as a monomer, plasticizer, or additive in different containers, serving as the primary structural component (Konieczna, 2015). When BPA is utilized, it enhances flexibility and chemical resistance in epoxy resins and other coatings, often found in food and beverage containers. In contact with water, BPA can be released from the walls of the containers, which can be increased with environmental temperatures. When containers with significant levels of BPA are exposed to 30°C to 50°C, they leach from 20% to over 50% of BPA into their contents as a result (Ginter-Kramarczyk, 2022).

Furthermore, polycarbonate plastics are commonly used materials for food and beverage containers, stressing the widespread exposure to BPA (Sonavane, 2019). The first level of the experiment involves a stainless-steel container, represented as the control because it is BPA-free. The second level is a polycarbonate plastic container, which is expected to release higher BPA levels due to its monomeric structure. The third level is a tin-plated container which releases BPA due to the lining inside the bottle. The fourth level is aluminum with an epoxy resin container, where BPA can leach from the epoxy resin lining designed to prevent direct contact between the water and aluminum (Konieczna, 2015).

BPA is a small molecule made of two carbon rings with bonded oxygen and hydrogen attached to either end. BPA is produced by the condensation reaction of phenol and acetone, creating the industrial version used today (Ginter-Kramarczyk, 2022). Because of BPA's low polarity and hydrophobic nature, it has been shown to have very poor solubility in water (Ginter-Kramarczyk, 2022). Due to its poor solubility with water, the chemical bonds that hold chains of the BPA together undergo hydrolysis in an aqueous solution. When the intermolecular bonds break down, individual BPA molecules are released into the solution, increasing BPA concentrations in containers (Sonavane, 2019).

Materials and Methods

Four 12 oz containers were selected for testing: stainless steel, polycarbonate plastic, tin-plated steel, and aluminum with epoxy resin lining. Each container was filled with 12 oz of tap water at a controlled temperature of 20°C. After, each container was sealed and hand shook for 30 seconds to simulate everyday use.

The sealed containers were then heated to a temperature of 32.2°C for 12 hours. After the heating process, all containers were unsealed, and five drops of Bisphenol A Indicator Iron (III) Chloride were administered to each sample. After a waiting period of five minutes, BPA levels were measured using BPA testing swabs. The swabs were swiped along the inner surface of each container and then placed into the water sample. These swabs were compared to a standardized Bisphenol A color chart to determine the concentration of BPA in nanograms per milliliter (ng/mL).

The procedure was repeated 25 times for each container type. The collected data were assessed through an ANOVA test and One-Way T-tests to compare and analyze the differences in mean BPA levels across the different container materials.

Following data collection, all materials, including water samples and BPA testing materials, were disposed of responsibly according to ethical guidelines of the *Environmental Protection Agency (EPA) Guidelines for the Disposal of Laboratory Chemicals.*

Results

The effect of container material on BPA production was determined to investigate how different materials influence the release of Bisphenol A under thermal conditions. To establish the relevance of polycarbonate plastic in contributing to BPA release, stainless steel was used as a negative control due to its BPA-free composition. Groups with polycarbonate plastic, tin-plated bottles, and aluminum with epoxy resins were given thermal exposure (32.2°C) to evaluate BPA leaching.

Compared to the group using stainless steel containers, the polycarbonate plastic group showed higher levels of BPA production ($p < 0.001$), suggesting that polycarbonate plastic is a contributor to BPA release. Additionally, the BPA levels in tin-plated bottles and aluminum with epoxy resins were very high compared to stainless steel containers ($p < 0.001$ for both comparisons), though lower than in polycarbonate plastics. Statistical analysis demonstrated that all differences were significant (t-statistics ranging from 14.78 to 145.44).

This method was chosen due to how the thermal and physical conditions presented in this experiment help replicate real-world scenarios where containers are created through plastics, tin, and aluminum.

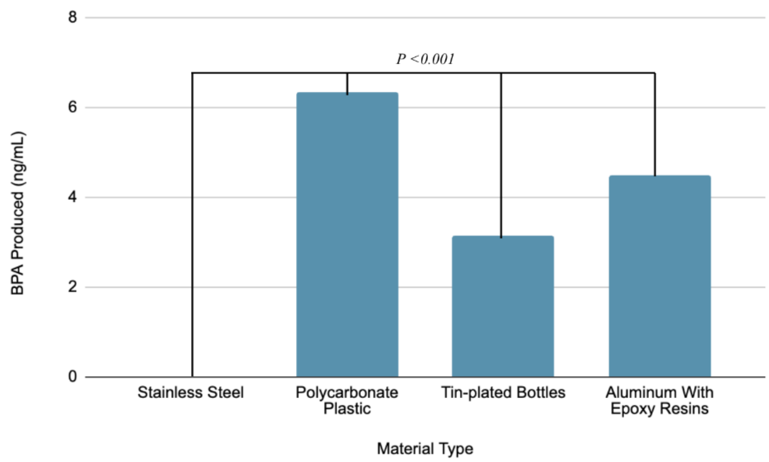

Figure 1. (25) BPA production rate of different materials with thermal pressure treated at 32.2°C. ANOVA test was performed to determine if a significant difference was present among the medians of the groups, and $p > 0.001$.

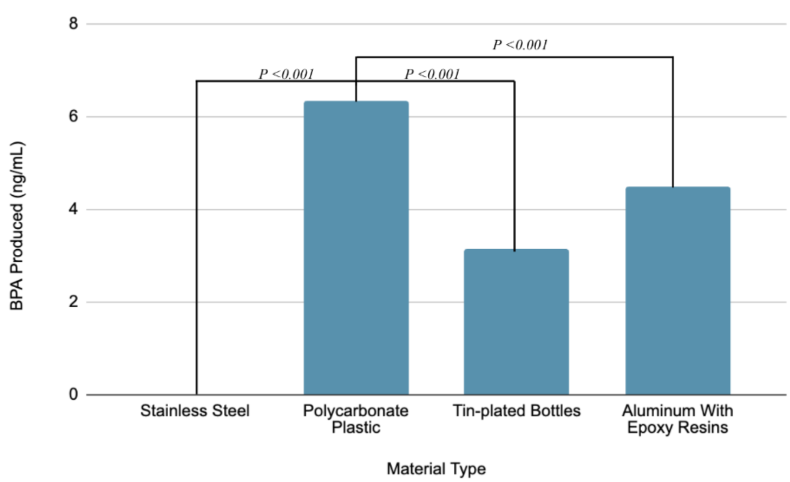

Figure 2. (25) BPA production rate of different materials with thermal pressure treated at 32.2°C. 3 one-tail t-tests were performed to determine if a significant difference was present among the medians of the groups, and $p > 0.001$.

Conclusion

The purpose of this experiment is to determine which container material releases the most Bisphenol A (BPA) when in contact with water at elevated temperatures, using polycarbonate plastic, aluminum with epoxy resins, tin-plated bottles, and stainless steel as the independent variable levels. By heating water-filled containers to 32.2°C and measuring BPA levels using a BPA testing kit, the study aimed to quantify BPA leaching under realistic conditions. This method was chosen because the thermal and physical conditions presented in this experiment help replicate real-world scenarios where containers composed of plastics, tin, aluminum, and steel are exposed. A research hypothesis was formulated stating that if the material, polycarbonate plastic, is used to contain water and kept in a warm environment (32.2°C), then it will have the most amount of Bisphenol A production. The data supported the research hypothesis due to polycarbonate plastics producing an average of 6.334 ng/mL of BPA compared to aluminum with epoxy resins with a mean of 4.488 ng/mL, tin-plated bottle at a 3.14 ng/mL average, and stainless steel with an average of 0 ng/mL. An ANOVA test and 3 different one-tail t-tests were performed to determine that the collected data of diverse containers in a heated environment on BPA production was statistically significant. All results gained were due to the independent variable and all tests were statistically significant, solidifying the data collected.

This study includes novelty through the approach of its experimentation. Specifically, it mimicked everyday consumer use. Samples were heated to 32.2°C, a temperature commonly reached in warm climates or during transportation. Containers were also shaken to simulate everyday handling. While previous research has focused on individual materials or extreme conditions, this study provides a comparison of commonly used container materials, emphasizing polycarbonate plastic's high BPA output in practical settings. Additionally, the statistical aspect of the experiment, as demonstrated by significant t-tests and ANOVA results, offers validation of the findings. This allows for further studies that could explore other factors influencing BPA leaching.

The results of this study help open new doors by providing data comparison of BPA release across multiple container materials. Seen through the data, it is emphasized that the molecular structure of polycarbonate plastic, which includes weak ester bonds, makes it vulnerable to hydrolysis and thermal degradation. On the other hand, materials such as stainless steel do not contain these susceptible bonds and thus show no detectable BPA leaching. This aids in reinforcing the chemical rationale behind the amount of BPA released in different materials and outlines how dangerous polycarbonate plastics are.

The results of this experiment were significant due to multiple factors that were carefully researched beforehand. An instance of this is seen when looking at the temperature each bottle sample would be in (32.2°C). Scientist Ginter-Kramarczyk states temperature is an effective factor in increasing the leaching of BPA from numerous materials, especially at high temperatures (Ginter-Kramarczyk, 2022). This shows how temperature helped release a higher amount of BPA, increasing the longevity of the results. Another factor that was carefully chosen was the materials being tested. Each independent variable level was thoroughly researched on how commonly individuals use it and how much BPA it normally contains. Through proper research and a well-planned experiment, the results were significant.

In conclusion, this study identifies the consequences of BPA leaching from various container materials under realistic conditions. The results that were gathered help advocate for the role of material composition in determining the safety of containers that are related to human consumption. As of now, polycarbonate plastics pose the greatest risk due to their structural susceptibility to thermal and hydrolytic degradation. Through the comparative data gained, this study helps pursue the goal of understanding BPA leaching, leading to a future of safer container materials and reducing BPA exposure globally.

Limitations

Though this experiment went well, numerous conflicts arose. One limitation seen is the consistency in the designs of the samples. For instance, stainless steel containers are used for durability, while plastic bottles are designed for one-time use. The differences in design use might have influenced the results. Another issue is that 12 oz containers may not fully show the proper BPA exposure risks. This is because the containers are of different shapes, leading to differences in surface-are-to-volume ratios and container thickness. This inconsistency might alter BPA release rates, limiting the study's relevance. Additionally, a major issue arose because of water spillage during BPA testing. The closeness of the test samples caused accidental spills, potentially influencing the measurement of BPA in the results. Lastly, the experiment did not account for real-world factors. This includes long exposure times of samples, pH variations, or the presence of additional substances, which could alter the BPA leaching rates. Understanding the missteps that occurred and including the solutions in future studies will allow for a better understanding of BPA release.

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